Conceptual optimal design of jackets

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Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

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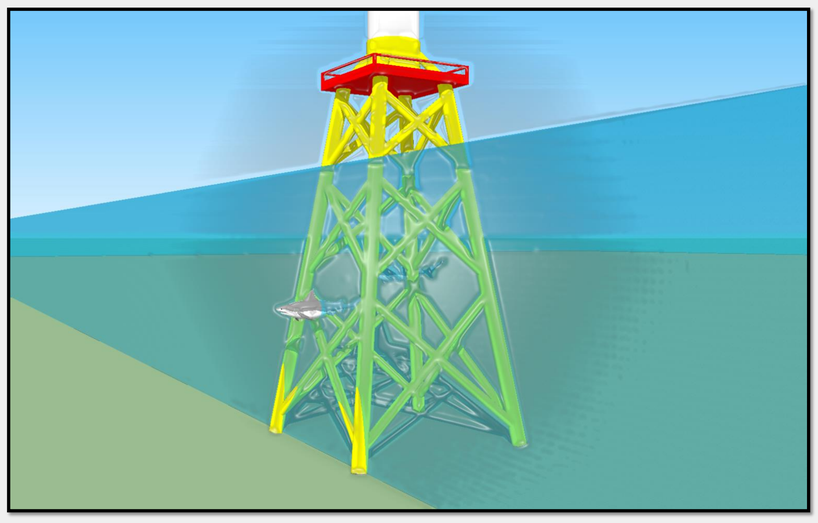

Figure 1: A jacket in its natural environment.

Structural optimization can explore a large design space (400 jackets) in a short time (2 hours), and thus lead to better conceptual jacket designs.

Motivation

Conceptual design describes the jacket in rough terms [1], such as height, width, and number of legs. This study investigates the influence of leg distance on optimized jacket mass.

Model & Software

In the research project ABYSS, a Timoshenko beam finite element software, JADOP, is developed for structural optimization of jackets. Main features of JADOP are

- Analytic sensitivities
- Parametric jacket topology
- Realistic wind and wave loads
- Fatigue post processing
- Stress concentration factors
- Advanced optimization

Optimization problem

Minimize the mass of a jacket, subject to fatigue constraints:

$$
\begin{aligned}
\text{minimize} \quad & f(\boldsymbol{x}) && \textit{Objective (mass)} \\
\text{subject to} \quad & \mathbf{K}(\boldsymbol{x})\boldsymbol{u} - \Delta\boldsymbol{P} = \mathbf{0} && \textit{State equation} \\
& \underline{\boldsymbol{\sigma}} \leq \Delta\boldsymbol{\sigma}(\boldsymbol{x}) \leq \overline{\boldsymbol{\sigma}} && \textit{Fatigue (stress)} \\
& \underline{\lambda} \leq \lambda_1(\boldsymbol{x}) \leq \overline{\lambda} && \textit{Frequency} \\
& \underline{\boldsymbol{x}} \leq \boldsymbol{x} \leq \overline{\boldsymbol{x}} && \textit{Design variables} \\
& \underline{\boldsymbol{u}} \leq \boldsymbol{u} \leq \overline{\boldsymbol{u}} && \textit{State variables}
\end{aligned}
$$

where $\boldsymbol{x}$ describes all the cross sections in the jacket, and $\Delta\boldsymbol{\sigma}(\boldsymbol{x}) \leq \overline{\boldsymbol{\sigma}}$ is a fatigue equivalent stress constraint.

The influence of leg distance on jacket mass

400 conceptual jacket designs with small changes in the top and bottom leg distances are created and optimized in JADOP. Figure 2 and 3 shows two of them. Figure 4 shows the trends for mass and frequency.

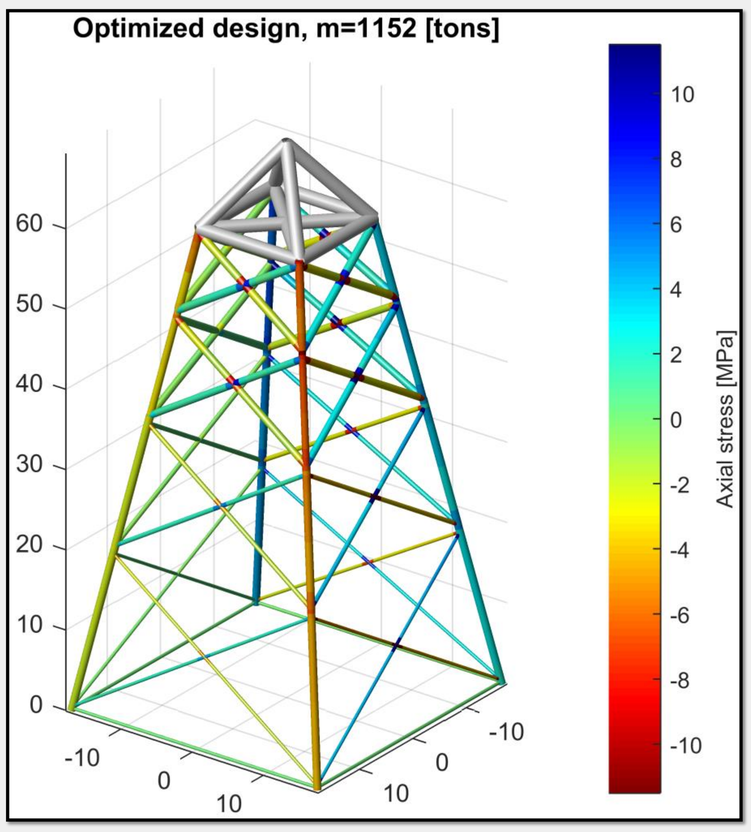

Figure 2: The Innwind reference jacket has a bottom and top leg distance of 34 and 14 meters, marked with a blue circle in Figure 5.

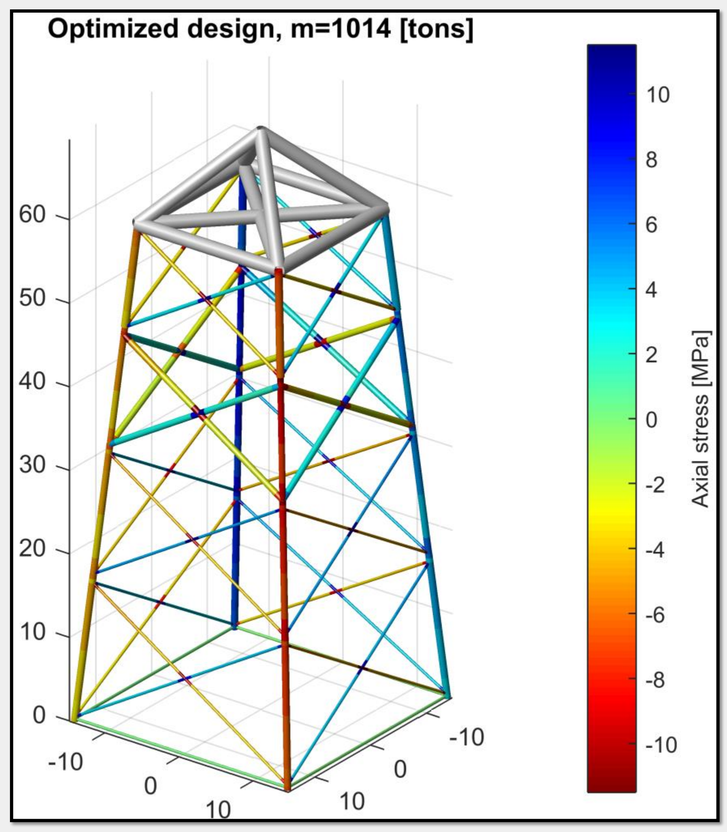

Figure 3: The new conceptual jacket has bottom and top leg distance of 28 and 19 meters, marked with a red star in Figure 5

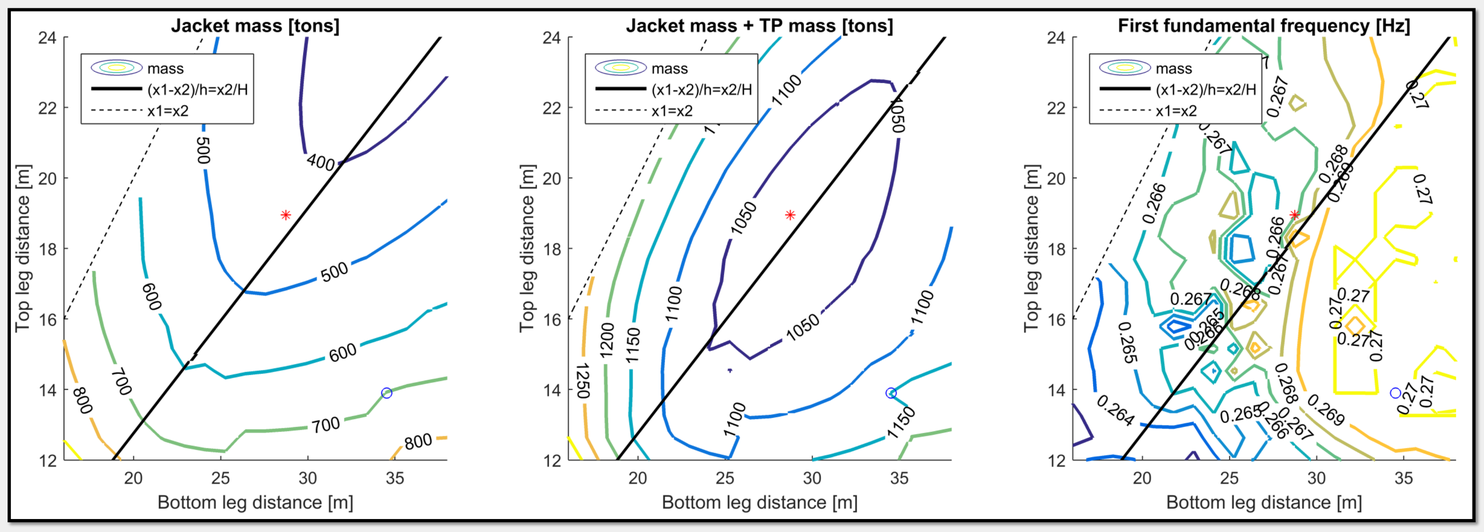

Figure 4: Three contour plots showing how the leg distance influences the optimal design of the support structure. Note how larger leg distance really influences the jacket mass, while frequency is almost unchanged. The black line indicates jackets where the extended legs would meet at the tower top.

References

[1] Marc Seidel. State-of-the-art design processes for offshore wind turbine support structures. Stahlbau, 85(9):583–590, 2016.
[2] Thomas von Borstel. Design report - reference jacket. Technical report, 2013
[3] A Waechter and L T Biegler. On the Implementation of a Primal-Dual Interior Point Filter Line Search Algorithm for Large-Scale Nonlinear Programming. Mathematical Programming, 106(1):25–57, 2006.